TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 289

PRELIMINARY BIPLANE TESTS IN THE VARIABLE DENSITY WIND TUNNEL

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Washington
June, 1928

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Summary

Biplane cellules using the N.A.C.A.-M6 airfoil section have been tested in the variable density wind tunnel of the National Advisory Committee for Aeronautics. Three cellules, differing only in the amount of stagger, were tested at two air densities, corresponding to pressures of one atmosphere and of twenty atmospheres. The range of angle of attack was from -2° to $+48^{\circ}$. The effect of stagger on the lift and drag, and on the shielding effect of the upper wing by the lower at high angles of attack was determined.

Introduction

Confirmations of the biplane theory, and the various empirical biplane corrections in general use, have for the most part been obtained in atmospheric wind tunnels. The present series of tests was conducted in order to find what effect the dynamic scale has on the aerodynamic characteristics of biplane cellules similar to those in general use, and to determine the advisability of a more extended biplane research in the variable density wind tunnel. It was also desired to find the effect of positive stagger at large angles of attack, for use in the study of stalled flight and tail spins.

Method and Apparatus

Two duralumin models of the N.A.C.A.-M6 airfoil, having 5-inch chord and 30-inch span, were assembled on duralumin N-struts to form the biplane cellule. Three sets of N-struts, designed to give staggers of zero, 15 degrees and 30 degrees, were used. As will be seen in Figure 1, the airfoils were made with trailing edge flaps. The flap hinges were pinned in the neutral position for these tests, giving the normal M6 airfoil except for the slight groove at the hinge.

The model was mounted in a manner similar to that generally used in this tunnel, described in Reference 1. In order to reach angles of attack of 48 degrees, the vertical supports were hinged at points 15 inches below the point of attachment to the lower wing of the cellule. Streamlined shields fastened to the tunnel floor were placed over the part of the supports below the hinge.

Two runs were made on the cellule for each set of N-struts, using pressures in the tank enclosing the tunnel (Reference 1) of one atmosphere and twenty atmospheres. The angle of attack was varied from -2° to $+32^\circ$ by 2° intervals, and from $+32^\circ$ to $+48^\circ$ by 4° intervals. Since the counterweight on the drag bridge of the balance (Reference 1) was insufficient for the drags obtained at the higher angles, the twenty-atmosphere runs were made in two parts. The first, with the normal counterweight covered the lower angles, up to values of the gross drag of 45 kg (99.2 lb.). For the second part an additional counterweight of 50 kg (110.2 lb.) was placed on the drag bridge, and the test continued to 48° angle of attack. The usual data, permitting computation of lift, drag, and pitching moment coefficients were obtained for each angle of attack.

Results

The data from the tests, reduced to absolute coefficients, will be found in Tables I to VI. The curves of C_D, and L/D, plotted against lift coefficients as ordinates, are given for the one-atmosphere tests in Figure 2, and for the twenty-atmosphere tests in Figure 3. Since the drag coefficients become very large at the higher angles, these figures only show the drag curves to a few degrees past the burble point. The "true" polar curves, i.e., with equal scales of lift and drag coefficients, will be found for the full range of angles in Figures 4 and 5. The curves of C_M plotted against lift coefficient are given in Figure 6.

Using the Prandtl correction for the tunnel walls (Reference 2):

$$C_{D_i} = \frac{C_L^2 \ S}{\pi \ k^2 \ b^2} \left(1 - \frac{k^2 \ b^2}{2 \ D^2}\right)$$

where C_{D_i} = induced drag coefficient

C_L = lift coefficient

D = throat diameter of tunnel = 60 in.

S = area = 300 sq.in.

k = biplane coefficient = 1.11

b = span = 30 in.

Then the induced drag coefficient

$$\bar{C}_{D_i} = \frac{C_L^2}{\pi}\left(\frac{S}{k^2\ b^2} - \frac{S}{2\ D^2}\right)$$

Substituting the above values

$$C_{D_i} = \frac{C_L^2}{\pi}\ (.2284) = \frac{C_L^2}{k^2\pi}\ (.282)$$

the induced drag of the biplane in free air is

$$C_{D_i} = \frac{C_L^2\ S'}{\pi \cdot k^2\ b'^2}$$

This data is then directly applicable to a biplane in free air for which

$$\frac{S}{b'^2} = .282$$

The aspect ratio of one wing of a biplane with equal wings is $\frac{2\ b^2}{S}$, therefore the aspect ratio of one wing of the equivalent biplane in free air is $\frac{2}{.282} = 7.10$.

The value of k, which depends upon the span-gap ratio, is taken from empirical data (Reference 3). Since a constant k is assumed the span-gap ratio of the equivalent biplane in free air will also be 6, the same as that of the wind tunnel model.

The curves of profile drag coefficient computed from the twenty atmosphere tests plotted against lift coefficient are shown in Figure 7. On this sheet is plotted also the profile drag coefficient for an M6, 5" x 30", monoplane tested at approximately the same Reynolds Number. The equations used to obtain the profile drag, corrected for tunnel wall effect by the Prandtl formula (Reference 2) are:

$$\text{Profile drag coefficient} = C_{D_p} = C_D - C_{D_i}$$

$$C_{D_i} \text{ (for the biplane)} = \frac{C_L^2 \; S}{\pi \; k^2 \; b^2} \left(1 - \frac{k^2 \; b^2}{2 \; D^2}\right)$$

$$C_{D_i} \text{ (for the monoplane)} = \frac{C_L^2 \; S'}{\pi \; b^2} \left(1 - \frac{b^2}{2 \; D^2}\right)$$

Values of S, b^2, and D are the same as given above; S' for the monoplane = 150 sq.in. C_{D_p} is plotted for each of the biplane arrangements using $k = 1.11$. For the condition of zero stagger C_{D_p} is also plotted using $k = 1.15$, as is explained below.

Discussion

Figures 2 and 3 show that the drag coefficient, over the useful range of the airfoil, becomes greater with increasing stagger. This is particularly true at the higher lift coefficients, which indicates that stagger increases the induced drag, probably because of the downwash of the upper wing affecting the lower wing more as the latter is displaced aft. The dynamic scale seems to have little effect on this phenomenon.

The order of maximum lift coefficient of the cellules is reversed by increasing the scale from that of the one atmosphere test to that of the twenty. The unstaggered cellule shows the greatest maximum lift coefficient at twenty atmospheres while the cellule with 30° stagger shows the greatest at one atmosphere. At very large angles of attack the lift coefficient and drag coefficient both are increased by increasing stagger, regardless of the scale of the test. This is to be expected, since increasing stagger decreases the amount of shielding of the upper wing by the lower, thus increasing the resultant force.

The coefficient of the moment about the quarter point of the mean chord of each cellule is nearly constant over the useful range of the lift coefficient. On account of the stable characteristics of the M6 airfoil the moment coefficient is very small in all cases. Increasing stagger has the effect of displacing the moment coefficient in the positive direction, for the range in which C_M is approximately constant. This is no doubt caused by the downwash of the upper wing acting on the lower, giving an effect somewhat like that of negative decalage.

Figure 4 shows that the profile drag coefficient of the two staggered cellules, obtained by using the value 1.11 for k, agrees very well with test of the M6 monoplane. At values near zero lift the C_{D_p} of the biplanes is higher than that of the monoplane, probably because of the drag and interference of the

N-struts, for which no correction has been made. Accurate determination of the profile drag coefficient at the higher lift coefficients is more difficult, and the consequent scattering of points is of the same order as this difference at zero lift; however, the curves lie very close together until maximum lift is approached. The agreement justifies the assumption of this value of k for the two staggered cellules, since the experimental method of determining k consists of choosing one which will give a profile drag curve checking that of a monoplane of the section in question.

The unstaggered biplane, however, using $k = 1.11$, shows a much lower profile drag than the monoplane or the staggered biplanes, for the range of C_L between .5 and 1.2. The discrepancy, which increases with increasing C_L, is so large that apparently the value of $k = 1.11$ gives too great induced drag for this cellule. The value of k required to bring this curve into agreement with the others was determined, and found to be 1.15, which is about the same as the theoretical maximum value of k for span-gap ratio 6 given in Reference 3. Using this value the profile drag curve of the unstaggered cellule agrees very well with those of the staggered cellules using $k = 1.11$, and of the monoplane. Consequently, it is only reasonable to conclude that the area of the equivalent air stream is actually larger for the unstaggered cellule than for those with stagger, resulting in a lower induced drag for a given lift coefficient.

C o n c l u s i o n s

The results of the twenty atmosphere test are directly applicable to a full scale biplane in free air of span-gap ratio 6, and aspect ratio of each wing of 7.10. They include the drag and interference of two N-struts.

While this set of tests is not sufficiently complete to be conclusive, it gives the following indications: that positive stagger increases the induced drag; that it decreases the maximum lift at Reynolds Numbers near full scale; and that it displaces the moment coefficient in the positive direction. Since these conclusions concerning lift and drag are directly contrary to the empirical corrections now in general use, further data is desirable, and a more extensive research on biplanes with various combinations of gap, stagger, and decalage will be made in the variable density tunnel in the near future.

Langley Field, Va.,

April 6, 1927.

Pub. June 1928 ?

B i b l i o g r a p h y

Reference 1.	Munk, Max M. and Miller, Elton W. :	The Variable Density Wind Tunnel of the National Advisory Committee for Aeronautics. N.A.C.A. Technical Report No. 227. (1925)
Reference 2.	Prandtl, L. :	Applications of Modern Hydrodynamics to Aeronautics. Part II, Sections E and F. N.A.C.A. Technical Report No. 116. (1921)
Reference 3.	Munk, Max M. :	General Biplane Theory. N.A.C.A. Technical Report No. 151. (1922)

TABLE I.

M6 biplane
Zero stagger
Av. tank press. = 1 atm.
Av. dynamic press.=25.2 kg/m²
Av. Reynolds Number = 173,000
Av. temperature = 19°C.

Span = 30 in. (76.2 cm)
Chord = 5 in. (12.7 cm)
Gap = 5 in. (12.7 cm)
Effective aspect ratio=7.10
Area = 0.1936 m² 300 in²
Date = Nov. 24, 1926.

Angle of attack degrees	Lift coefficient C_L	Drag coefficient C_D	Ratio L/D	Moment coefficient C_M (about 25% mean chord)
-2	-.044	+.0220	-2.00	-.012
0	+.056	.0186	+3.01	-.024
+2	.203	.0189	10.75	+.001
4	.356	.0247	14.41	-.007
6	.472	.0324	14.56	-.018
8	.597	.0413	14.45	-.025
10	.725	.0547	13.25	+.017
12	.814	.0689	11.81	-.007
14	.896	.0830	10.79	+.011
16	.901	.0994	9.06	.000
18	.888	.1499	5.92	-.023
20	.810	.2300	3.52	-.065
22	.718	.2909	2.47	-.089
24	.693	.3292	2.10	-.095
26	.675	.3643	1.85	-.107
28	.675	.3951	1.71	-.114
30	.684	.4380	1.56	-.125
32	.705	.4746	1.49	-.113
36	.711	.5526	1.29	-.154
40	.698	.6142	1.14	-.159
44	.655	.6566	1.00	-.166
+48	+.596	+.6992	+ .85	-.198

TABLE II.

M6 biplane
Zero stagger
Av. tank press. = 21.0 atm.
Av. dynamic press. = 552 kg/m²
Av. Reynolds Number = 3,400,000
Av. temperature = 39°C.

Span = 30 in. (76.2 cm)
Chord = 5 in. (12.7 cm)
Gap = 5 in. (12.7 cm)
Effective aspect ratio=7.10
Area = 0.1936 m²
Date = Nov. 24, 1926.

Angle of attack, degrees	Lift coefficient C_L	Drag coefficient C_D	Ratio L/D	Moment coefficient C_M (about 25% mean chord)
-2	-.085	+.0143	-5.94	-.016
0	+.043	.0127	+3.38	-.005
+2	.164	.0143	11.55	-.001
4	.298	.0185	16.11	+.011
6	.424	.0246	17.24	+.014
8	.547	.0331	16.47	+.012
10	.676	.0454	14.86	+.003
12	.800	.0583	13.72	+.008
14	.917	.0742	12.37	-.003
16	1.037	.0946	10.96	+.003
18	1.133	.1138	9.97	+.007
20	1.225	.1362	9.03	+.015
22	1.242	.1762	7.06	+.007
24	1.185	.2497	4.73	-.053
26	1.061	.3199	3.32	-.067
28	.949	.3646	2.60	-.093
30	.865	.4121	2.10	-.112
32	.729	.4439	1.64	-.117
36	.757	.5677	1.38	-.144
40	.709	.6190	1.14	-.144
44	.645	.6508	.99	-.129
+48	+.575	+.6558	+.88	-.107

TABLE III.

M6 biplane
15° stagger
Av. tank press. = 1 atm.
Av. dynamic press. = 25.2 kg/m²
Av. Reynolds Number = 173,000
Av. temperature = 20°C.

Span = 30 in. (76.2 cm)
Chord = 5 in. (12.7 cm)
Gap = 5 in. (12.7 cm)
Effective aspect ratio=7.10
Area = 0.1936 m²
Date = Dec. 2, 1926.

Angle of attack degrees	Lift coefficient C_L	Drag coefficient C_D	Ratio L/D	Moment coefficient C_M (about 25% mean chord)
-2	-.044	+.0229	-1.92	-.010
0	+.070	.0210	+3.33	-.001
+2	.221	.0221	10.00	-.003
4	.367	.0296	12.40	-.008
6	.496	.0363	13.66	+.011
8	.617	.0473	13.05	-.014
10	.732	.0595	12.30	-.029
12	.822	.0739	11.12	-.022
14	.900	.0909	9.90	+.003
16	.932	.1059	8.80	+.002
18	.922	.1515	6.09	-.018
20	.834	.2279	3.66	-.048
22	.784	.3004	2.61	-.090
24	.748	.3521	2.12	-.132
26	.755	.3999	1.89	-.155
28	.732	.4311	1.70	-.163
30	.739	.4720	1.57	-.160
32	.746	.5089	1.47	-.178
36	.752	.5958	1.26	-.232
40	.754	.6713	1.12	-.259
44	.714	.7341	.97	-.269
+48	+.679	+.7993	+.85	-.285

TABLE IV.

M6 biplane
15° stagger
Av. tank press. = 20.8 atm.
Av. dynamic press. = 581 kg/m²
Av. Reynolds Number = 3,510,000
Av. temperature = 34°C.

Span = 30 in. (76.2 cm)
Chord = 5 in. (12.7 cm)
Gap = 5 in. (12.7 cm)
Effective aspect ratio=7.10
Area = 0.1936 m²
Date = Dec. 3, 1926.

Angle of attack degrees	Lift coefficient C_L	Drag coefficient C_D	Ratio L/D	Moment coefficient C_M (about 25% mean chord)
-2	-.072	+.0140	-5.14	-.009
0	+.052	.0128	+4.06	-.003
+2	.175	.0143	12.30	.000
4	.300	.0182	16.50	+.011
6	.421	.0248	16.98	+.007
8	.541	.0341	15.90	+.005
10	.671	.0463	14.49	+.008
12	.785	.0599	13.11	+.009
14	.897	.0759	11.82	+.017
16	1.016	.0955	10.64	+.025
18	1.110	.1148	9.67	+.002
20	1.181	.1405	8.40	-.005
22	1.183	.1856	6.33	-.027
24	1.164	.2262	5.14	-.033
26	1.083	.2953	3.67	-.069
28	1.001	.3424	2.92	-.074
30	.894	---	---	-.084
32	.839	.4621	1.82	-.161
36	.788	.5461	1.44	-.168
40	.772	.6465	1.20	-.192
44	.722	.7018	1.03	-.185
+48	+.660	+.7444	+0.89	-.174

TABLE V.

M6 biplane
30° stagger
Av. tank press. = 1 atm.
Av. dynamic press. = 25.6 kg/m²
Av. Reynolds Number = 175,000
Av. temperature = 18°C.

Span = 30 in. (76.2 cm)
Chord = 5 in. (12.7 cm)
Gap = 5 in. (12.7 cm)
Effective aspect ratio=7.10
Area = 0.1936 m²
Date = Dec. 7, 1926.

Angle of attack degrees	Lift coefficient C_L	Drag coefficient C_D	Ratio L/D	Moment coefficient C_M (about 25% mean chord)
-2	-.042	+.0253	-1.66	-.001
0	+.071	.0195	+3.64	-.008
+2	.215	.0238	9.04	+.004
4	.363	.0286	12.69	-.007
6	.501	.0388	12.91	+.018
8	.619	.0496	12.47	-.019
10	.741	.0699	10.60	-.005
12	.846	.0839	10.08	+.021
14	.908	.0998	9.10	+.020
16	.935	.1261	7.41	-.010
18	.868	.2063	4.21	-.040
20	.837	.2450	3.42	-.066
22	.825	.2974	2.77	-.085
24	.810	.3592	2.25	-.135
26	.804	.4261	1.89	-.162
28	.798	.4661	1.71	-.145
30	.797	.5086	1.56	-.209
32	.801	.5473	1.46	-.203
36	.804	.6365	1.26	-.250
40	.805	.7245	1.11	-.276
44	.786	.8036	.98	-.293
+48	+.753	+.8838	+.85	-.366

TABLE VI.

M6 biplane
30° stagger
Av. tank press. = 20.76 atm.
Av. dynamic press. = 608 kg/m²
Av. Reynolds Number = 3,680,000
Av. temperature = 29°C.

Span = 30 in. (76.2 cm)
Chord = 5 in. (12.7 cm)
Gap = 5 in. (12.7 cm)
Effective aspect ratio = 7.10
Area = 0.1936 m²
Date = Dec. 7, 1926.

Angle of attack degrees	Lift coefficient C_L	Drag coefficient C_D	Ratio L/D	Moment coefficient C_M (about 25% mean chord)
-2	-.069	+.0138	-5.0	+.002
0	+.043	.0131	+3.4	.013
+2	.182	.0148	12.3	.008
4	.321	.0200	16.1	.031
6	.452	.0276	16.4	.022
8	.578	.0379	15.24	.033
10	.710	.0515	13.81	.022
12	.830	.0666	12.5	.025
14	.954	.0865	11.05	.017
16	1.063	.1062	10.00	.029
18	1.161	.1308	8.87	+.006
20	1.182	.1761	6.71	-.005
22	1.160	.2311	5.02	-.043
24	1.134	.2707	4.19	-.069
26	1.080	.3188	3.38	-.093
28	1.014	.3894	2.60	-.141
30	.984	.4495	2.19	-.185
32	.927	.5093	1.82	-.171
36	.864	.6052	1.43	-.205
40	.812	.6940	1.17	-.229
44	.776	.7587	1.02	-.225
+48	+.738	+.8297	+.89	-.243

TABLE VII.

Table of Ordinates

N.A.C.A.-M6 Airfoil

Station % chord from L.E.	Ordinate in % chord	
	Upper	Lower
0	.00	.00
1-1/4	+1.97	-1.76
2-1/2	2.81	-2.20
5	4.03	-2.73
7-1/2	4.94	-3.03
10	5.71	-3.24
15	6.82	-3.47
20	7.55	-3.62
30	8.22	-3.79
40	8.05	-3.90
50	7.26	-3.94
60	6.03	-3.82
70	4.58	-3.48
80	3.06	-2.83
90	1.55	-1.77
95	.88	-1.08
100	+.26	- .26

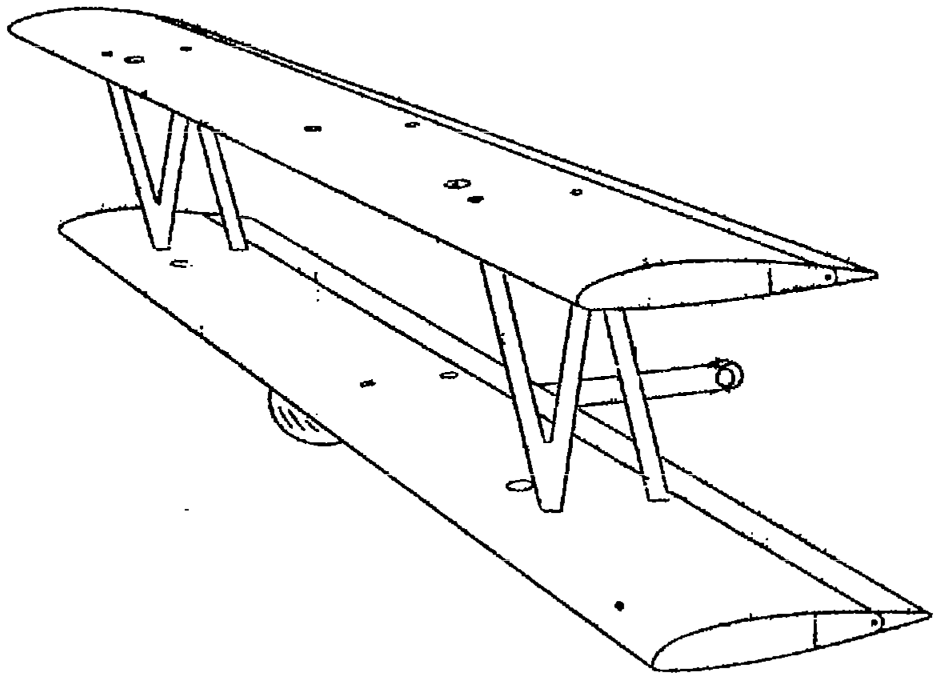

Fig.1 M-6 biplane with 15° stagger.

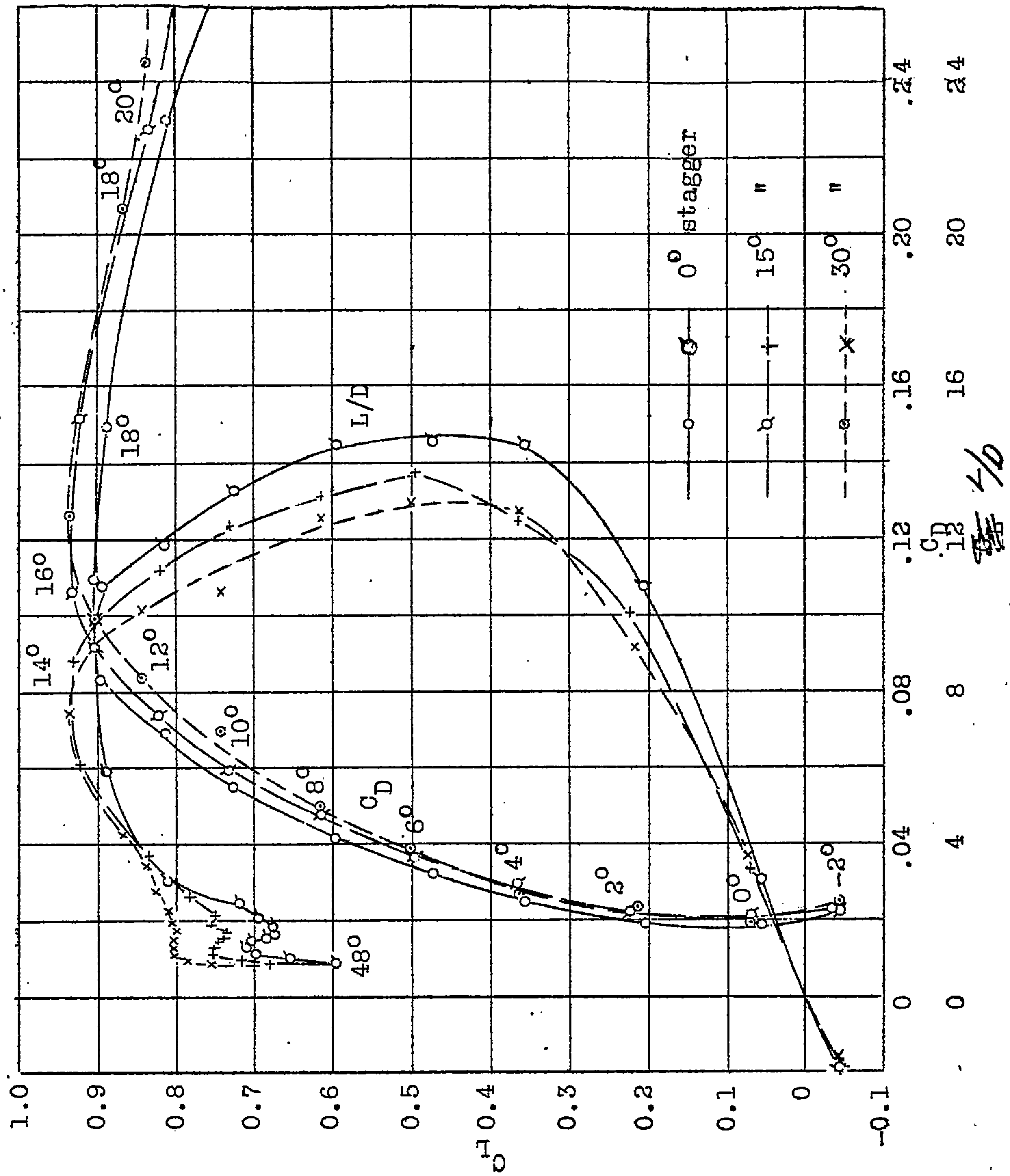

Fig.2 Polar and L/D curves. M-6,5" by 30" biplane.
5" gap. 1 Atmosphere. Average Reynolds No. 174,000.

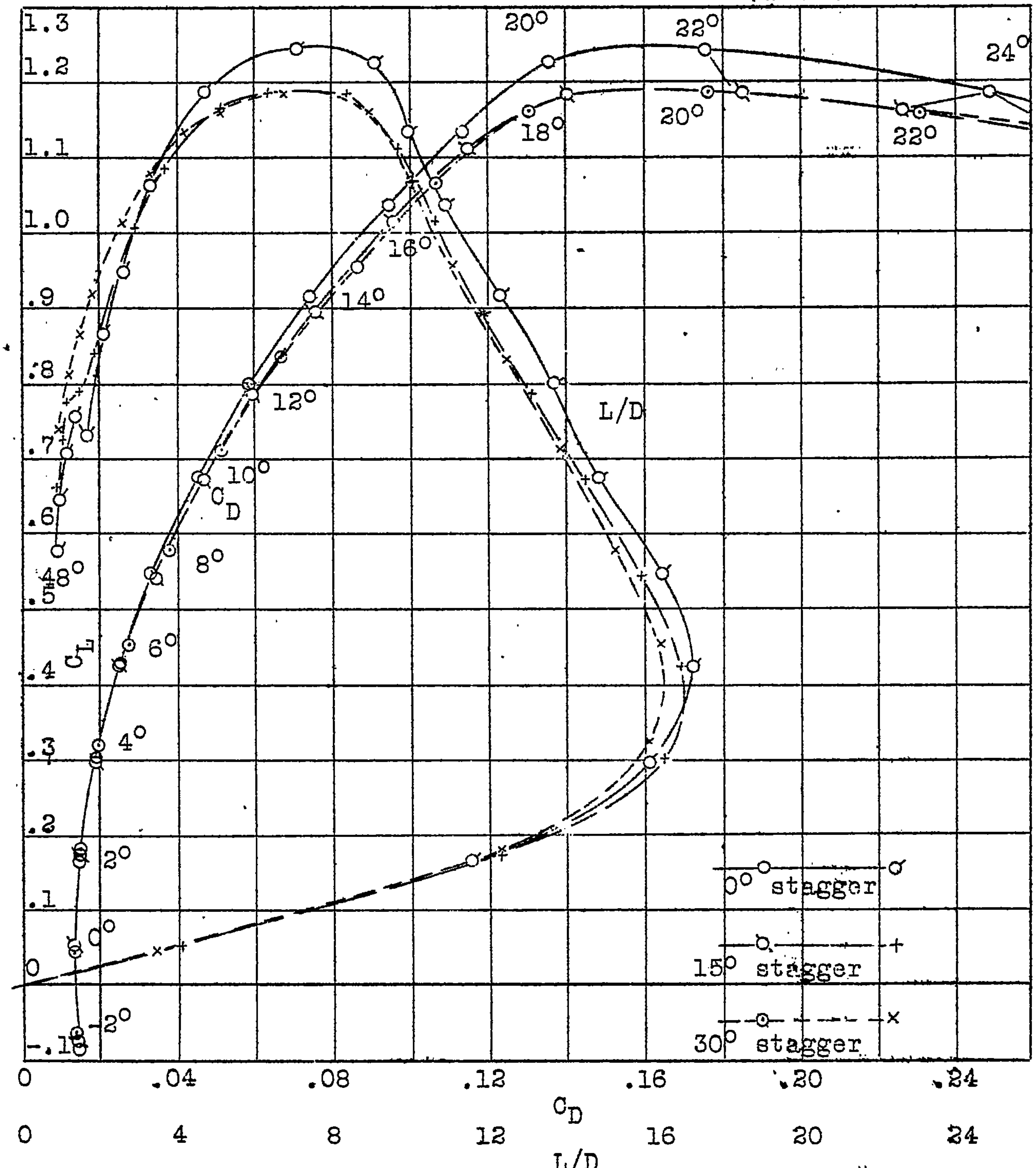

Fig.3 Polar and L/D curves. M-6,5" by 30" biplane. 5" gap. 20 atmospheres. Average Reynolds No.3,500,000.

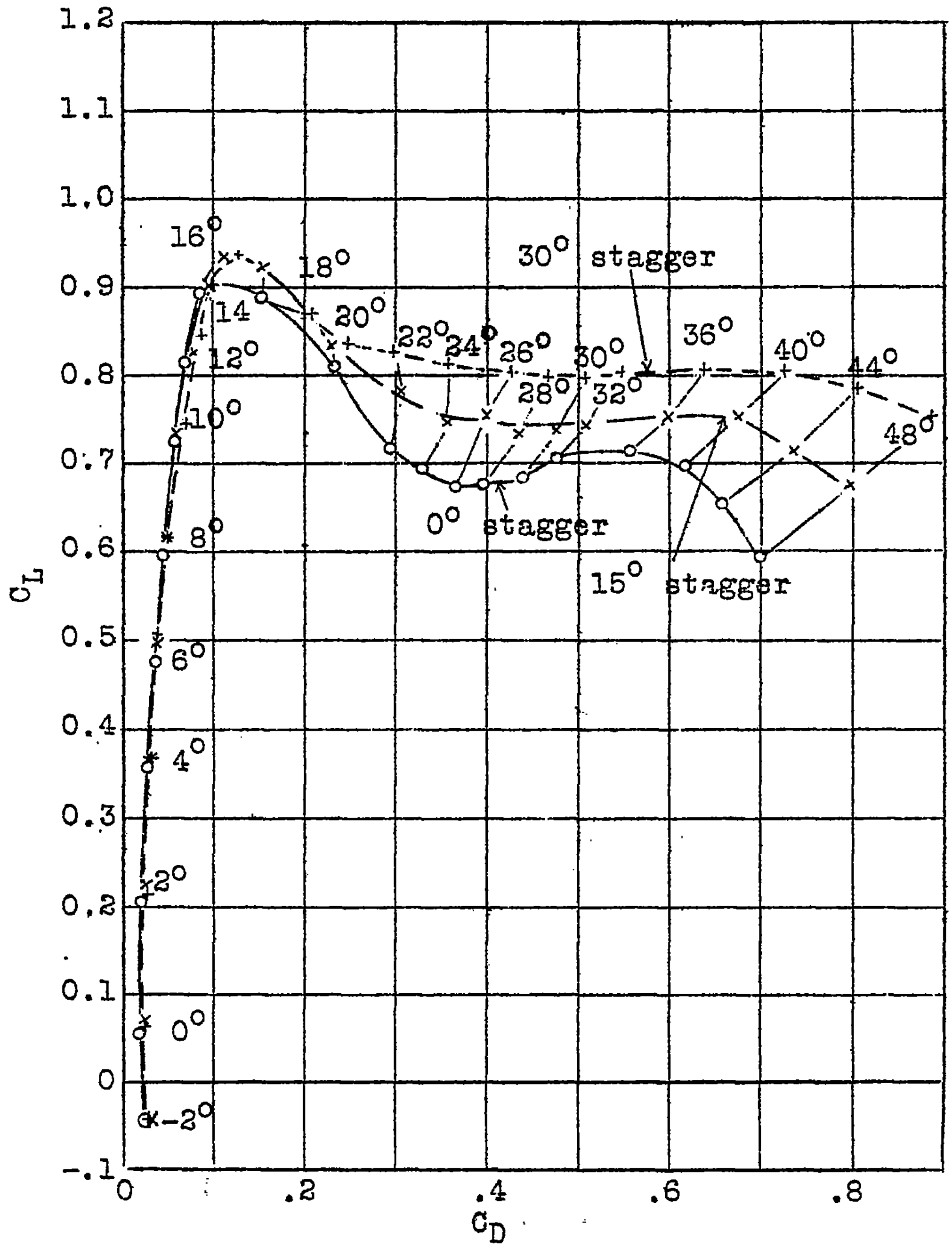

Fig.4 True polar curves. M-6,5" by 30" biplane. 5" gap. 1 atmosphere. Average Reynolds No. 174,000.

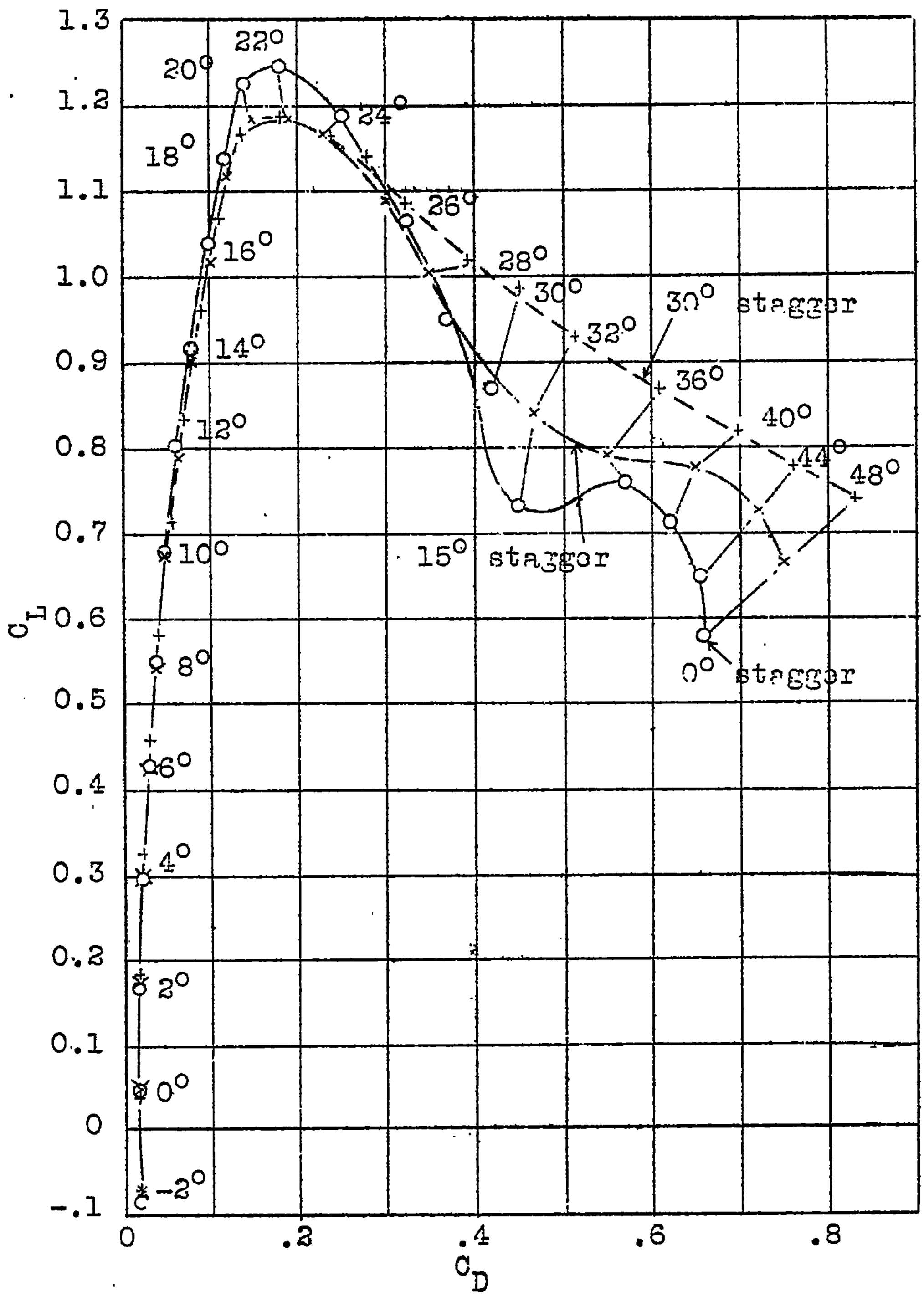

Fig.5 True polar curves. M-6 5" by 30" biplane. 5" gap. 20 atmospheres. Average Reynolds No. 3,500,000.

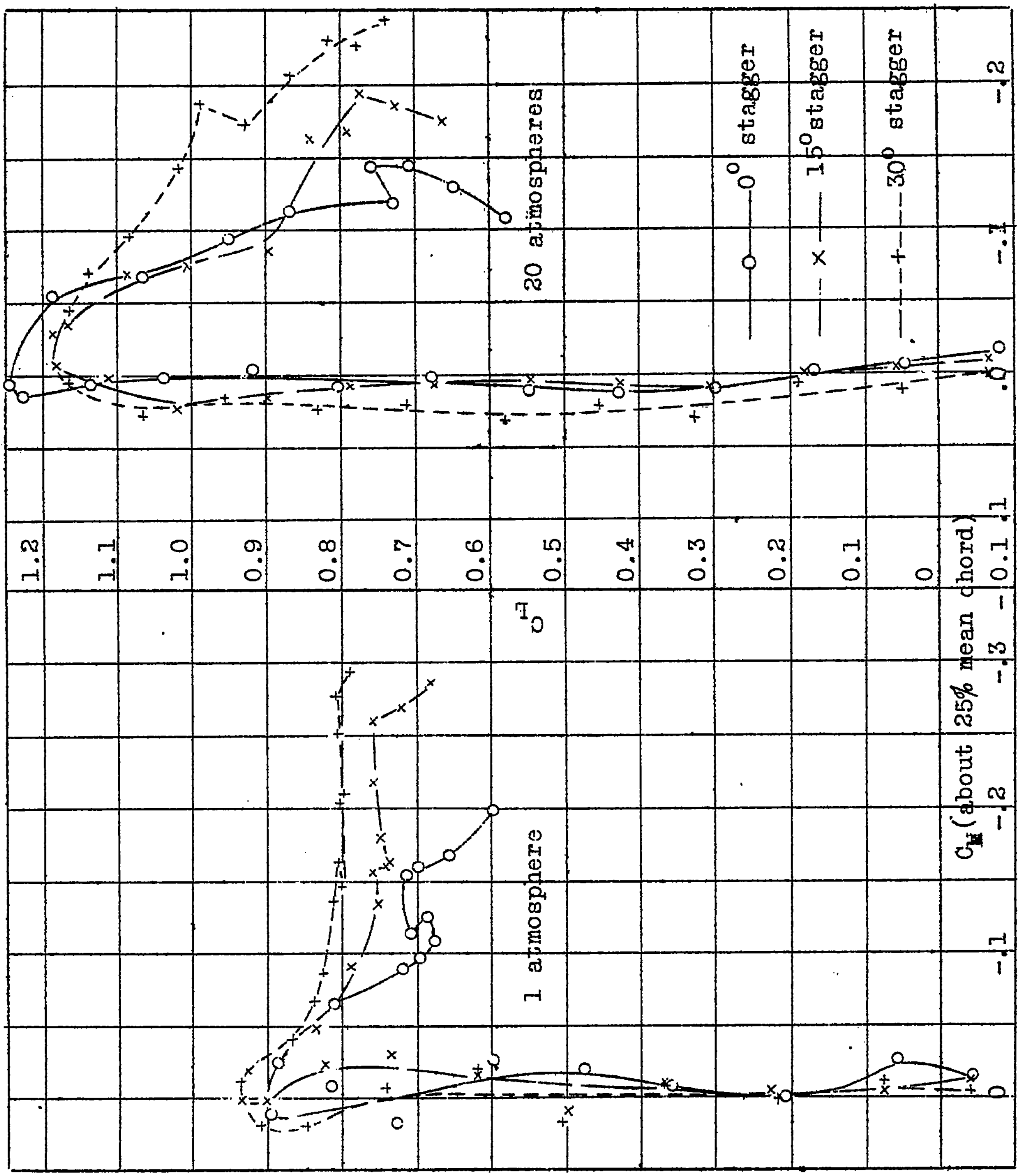

Fig.6 Moment coefficients. M-6,5" by 30" biplane. 5" gap.

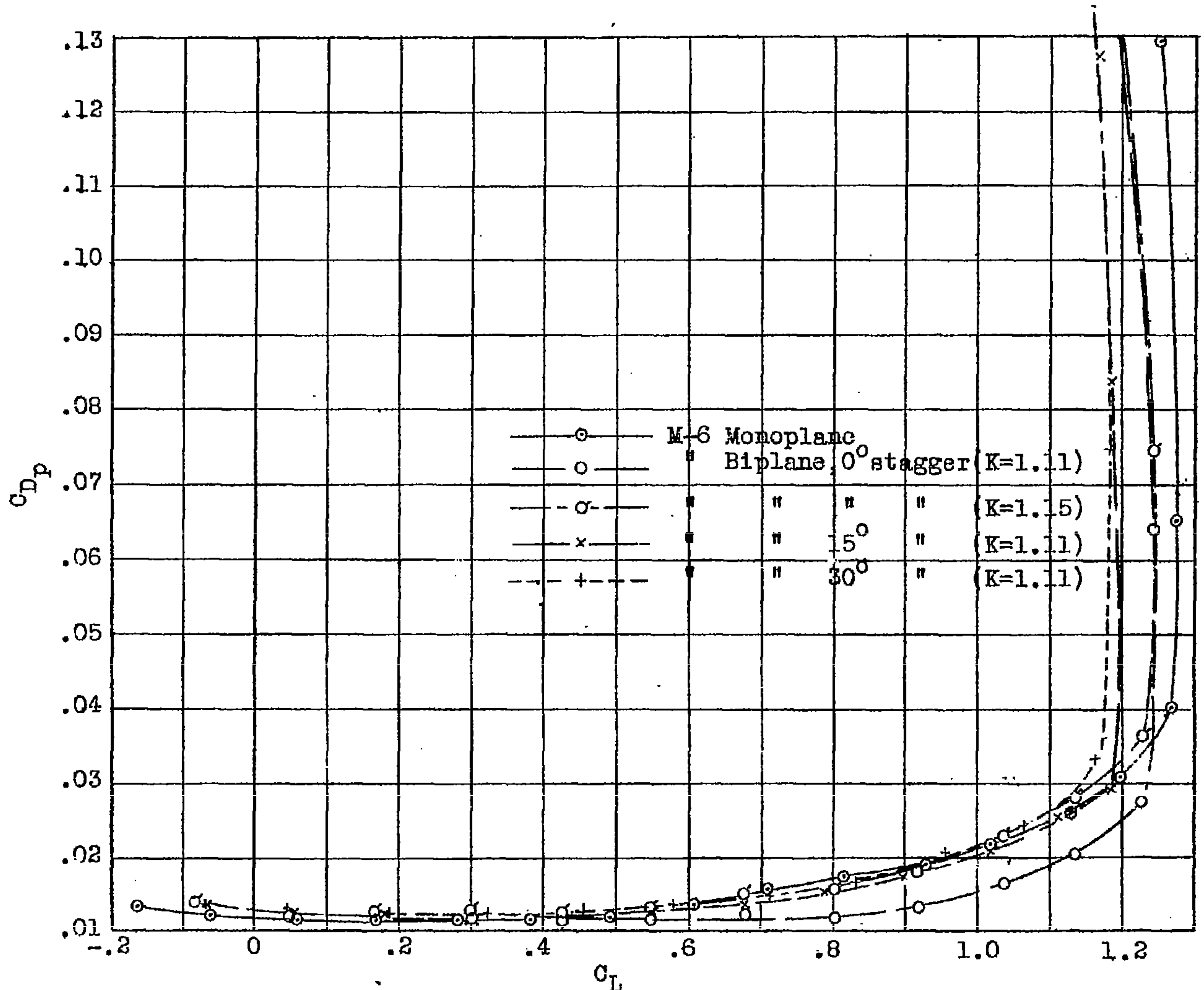

Fig.7 Profile drag coefficients. 20 Atmospheres. Average Reynolds No. 3,500,000.